Spin transfer in high energy fragmentation processes

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Abstract. We point out that measuring longitudinal polarizations of different hyperons produced in lepton induced reactions are ideal to study the spin transfer of the fragtmenting quark to produced hadron in high energy hadronization processes. We briefly summarize the method used in calculating the hyperon polarizations in these processes, then present some of the results for e^+e^- and e^-p or νp reactions obtained using two different pictures for the spin structure of hyperon: that drawn from polarized deep inelastic lepton-nucleon scattering data or that using SU(6) symmetric wave functions. The results show in particular that measurements of such polarizations should provide useful information to the question of which picture is more suitable in describing the spin effects in the fragmentation processes.

The talk was a summary of a series of papers [1-3] by C. Boros and ourselves. Spin transfer in high energy fragmentation process is defined as the probability for the polarization of the fragmenting quark to be transferred to the produced hadron. It is one of the important issue in connection with the spin effects in high energy fragmentation processes which have attracted much attention recently [4]. The problem contains the following two questions: (1) Will the polarization of the fragmenting quark be retained in the fragmentation process? (2) What is the relationship between the spin of the quark and that of the hadron which contains this quark? Clearly, the answers to these questions depend not only on the hadronization mechanism but also on the spin structure of hadrons. Study of such effects provide useful information for the spin structure of hadron and spin dependence of high energy reactions. There exist now two distinctively different pictures for the spin contents of the baryons: the static quark model picture using SU(6) symmetric wave function [hereafter referred as SU(6) picture], and the picture drawn from the data for polarized deep inelastic lepton-nucleon scattering (DIS) and SU(3) flavor symmetry in hyperon decay [hereafter referred as DIS picture]. It is particular interesting to ask which picture is suitable to describe the relationship between the polarization of the fragmenting quark and that of the produced hadron which contains this quark. Obviously, the answer to this question is essential in the description of the puzzling hyperon transverse polarization observed already in the

1970s in unpolarized hadron-hadron reactions [5].

It has been pointed out that [1,2] measurements of the longitudinal Λ polarization in e^+e^- annihilations at the Z^0 pole provide a very special check to the validity of SU(6) picture in connecting the spin of the constituent to the polarization of the hadron produced in the fragmentation processes. This is because the Λ polarization in this case obtained from the SU(6) picture should be the maximum among different models. There are now data with reasonably high statistics available from both ALEPH [6] and OPAL [7] Collaborations. Their results show that the SU(6) picture seems to agree better with the data [6,7] compared with the DIS picture. This is rather surprising since the energy is very high at LEP thus the initial quarks and anti-quarks produced at the annihilation vertices of the initial e^+e^- are certainly current quarks and current anti-quarks rather than the constituent quarks used in describing the static properties of hadrons using SU(6) symmetric wave functions. It is thus interesting and instructive to make further checks in experiments by making complementary measurements. For this purpose, we have made a systematic study of hyperon polarizations in different lepton-induced reactions using the SU(6) or the DIS picture. The results we obtained can be used as further check of the pictures and now we give a brief summary of the calculation method and the obtained results.

We first summarize the calculation method by taking $e^+e^- \to H_i + X$ as an example.

Since the longitudinal polarization P_{H_i} of the hyperon H_i in the inclusive process $e^+e^- \to H_i + X$ originates from the longitudinal polarization P_f of the initial quark q_f^0 (where the subscript f denotes its flavor) produced at the annihilation vertex of the initial state e^+e^-, we should consider the H_i's which have the following different origins separately.

(a) Hyperons which are directly produced and contain the initial quarks q_f^0's originated from the annihilations of the initial e^+ and e^-;

(b) Hyperons which are decay products of other heavier hyperons which were polarized before their decay;

(c) Hyperons which are directly produced but do not contain any initial quark q_f^0 from e^+e^- annihilation;

(d) Hyperons which are decay products of other heavier hyperons which were unpolarized before their decay.

It is clear that hyperons from (a) and (b) can be polarized while those from (c) and (d) are not. We obtain therefore,

$$P_{H_i} = \frac{\sum_f t^F_{H_i,f} P_f \langle n^a_{H_i,f} \rangle + \sum_j t^D_{H_i,H_j} P_{H_j} \langle n^b_{H_i,H_j} \rangle}{\langle n^a_{H_i} \rangle + \langle n^b_{H_i} \rangle + \langle n^c_{H_i} \rangle + \langle n^d_{H_i} \rangle}. \tag{1}$$

Here P_f is the polarization of the initial quark q_f^0, and is determined by the electroweak vertex; $\langle n^a_{H_i,f} \rangle$ is the average number of the hyperons which are directly produced and contain the initial quark of flavor f; $\langle n^b_{H_i,H_j} \rangle$ is the average number of H_i hyperons coming from the decay of H_j hyperons which are polarized;

P_{H_j} is the polarization of the hyperon H_j before its decay; $\langle n^a_{H_i}\rangle(\equiv \sum_f \langle n^a_{H_i,f}\rangle)$, $\langle n^b_{H_i}\rangle(\equiv \sum_j \langle n^b_{H_i,H_j}\rangle)$, $\langle n^c_{H_i}\rangle$ and $\langle n^d_{H_i}\rangle$ are average numbers of hyperons in group (a), (b), (c) and (d) respectively; $t^F_{H_i,f}$ is the probability for the polarization of q^0_f to be transferred to H_i in the fragmentation process and is called the polarization transfer factor, where the superscript F stands for fragmentation; $t^D_{H_i,H_j}$ is the probability for the polarization of H_j to be transferred to H_i in the decay process $H_j \to H_i + X$ and is called decay polarization transfer factor, where the superscript D stands for decay. $t^F_{H_i,f}$ is equal to the fraction of spin carried by the f-flavor-quark divided by the average number of quark of flavor f in the hyperon H_i. This fractional contribution to the hyperon spin from f-flavor-quark is different in the above-mentioned SU(6) or the DIS picture. The results in the SU(6) picture can easily be obtained from the wave functions. In the DIS picture, the fractional contribution of quarks of different flavors to the spin of a baryon in the $J^P = \frac{1}{2}^+$ octet is extracted from $\Gamma^p_1 \equiv \int_0^1 g^p_1(x)dx$ obtained in deep-inelastic lepton-proton scattering experiments and the constants F and D obtained from hyperon decay experiments. The way of doing this extraction is now in fact quite standard. A brief summay can, e.g., be found in the Appendix of [1]. The results can be found e.g. in [1,2]. The decay polarization transfer factor $t^D_{H_i,H_j}$ is determined by the decay process and is independent of the process in which H_j is produced.They can be extracted from the materials in Review of Particle Properties (see e.g. [8,1,2]).

The average numbers of the hyperons of different origins mentioned above are determined by the hadronization mechanism and should be independent of the polarization of the initial quarks. Hence, we can calculate them using a hadronization model which give a good description of the unpolarized data for multiparticle production in high energy reactions. Presently, such calculations can only be carried out using a Monte-Carlo event generator. We used the Lund string fragmentation model [9] implemented by JETSET in our calculations.

The method described above was first applied to $e^+e^- \to \Lambda + X$ at the Z^0 pole. We recall that among all the $J^P = \frac{1}{2}^+$ hyperons, Λ is most copiously produced. Furthermore, the spin structure of Λ in the $SU(6)$ picture is very special, which makes it play a very special role in distinguishing the SU(6) and the DIS pictures. In the $SU(6)$ picture, spin of Λ is completely carried by the s valence quark, while the u and d quarks have no contribution. Since the initial s quark produced in the annihilation of the initial e^+e^- takes the maximum negative polarization, $|P_\Lambda|$ obtained using the SU(6) picture is the maximum among all the different models. In contrast, in the DIS picture, the s quark carries only about 60% of the Λ spin, while the u or d quark each carries about -20%. The resulting $|P_\Lambda|$ should be substantially smaller than that obtained in the $SU(6)$ picture. Comparing the maximum with experimental results provide us a good test of the validity of the picture.

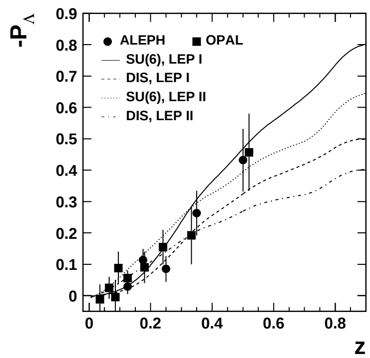

Fig.1: Longitudinal Λ polarization, P_Λ, in $e^+e^- \to \Lambda + X$ at LEP I and LEP II energies as a function of z. The data of ALEPH and those of OPAL are taken from [6] and [7] respectively.

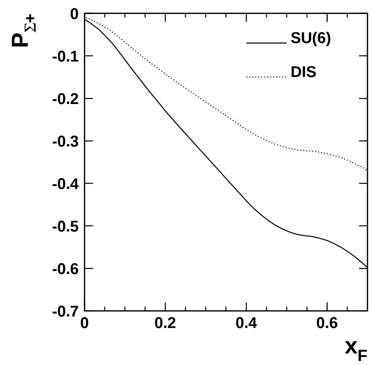

Fig.2: Longitudinal Σ^+ polarization, P_{Σ^+}, in $\nu_\mu + p \to \mu^- + \Sigma^+ + X$ at $p_{inc} = 500$GeV/c as a function of x_F.

Using the method described above, we obtained the longitudinal polarization of Λ as shown in Fig.1. A comparison with the ALEPH data [6] and the OPAL data [7] shows that the data [6,7] of both groups agree better with the calculated results based on the $SU(6)$ picture. But, these available data [6,7] are still far from accurate and enormous enough to make a decisive conclusion. Further complementary measurements are needed. We therefore made a systematic study of hyperon produced in different lepton-induced reactions and obtain in particular the following results which can be used as further checks of the pictures.

1.Λ polarization in different subsamples of events in $e^+e^- \to \Lambda + X$.

We think it would be interesting to measure Λ polarization in events where the following criteria are satisfied: (i) Λ is the leading in one direction; (ii) the leading particle in the opposite direction is K^+. We expect that such Λ's should mainly have the origin (a) mentioned above.

Using the event generator JETSET, we showed that the Λ's from (a) contribute indeed substantially higher in these events than they do in the average events and the obtained $|P_\Lambda|$ is also much higher [2]. This should be easily be check in experiments.

2. Energy dependence of P_Λ in $e^+e^- \to \Lambda X$.

To see the energy dependence, we calculated P_Λ in $e^+e^- \to \Lambda X$ at LEP II energy. The results are also shown in Fig.1. We see a significant energy dependence due to that of P_f of the initial quark q_f^0. This can also be checked.

3. Longitudinal polarization of other $J^P = \frac{1}{2}^+$ hyperons.

The production rates for other octet hyperons are smaller than that for Λ so the statistic errors should be larger for the polarizations of these hyperons. On the other hand, decay contributions from heavier hyperons to these hyperons are also much less significant than that in case of Λ. Hence, the contaminations from the decay processes are much smaller. These conclusions can easily be checked using

a Monte-Carlo event generator for e^+e^- annihilation into hadrons. On the other hand, we see also that the contribution from heavier hyperon decays is also much smaller. For example, for Σ^+'s, the decay contribution takes only about 7% of the total rate. The situations for Σ^-, Ξ^0, and Ξ^- are similar to that for Σ^+. Most of them are directly produced. Hence, the theoretical uncertainties in the calculations for these hyperons are much smaller. The study of polarizations of these hyperons should provide us with good complementary tests of different pictures. We thus calculated the longitudinal polarizations of all these $J^P = (1/2)^+$ hyperons[2], i.e., Σ^+, Σ^-, Ξ^0 and Ξ^-, in e^+e^- annihilation at LEP I and LEP II energies. We found that they are all polarized and the polarizations are different for different hyperons. They are also different in SU(6) picture and the DIS picture which can indeed be used as complementary check to the picture.

4. Hyperon polarization in the current fragmentation region in lepton-nucleon deeply inelastic scatterings.

The advantages of using hyperons in lepton-nucleon deeply inelastic scatterings are the following: First, we can study here not only longitudinal polarization transfer but also to check whether it is the same for transverse polarization case. Second, flavor separation is, in some cases, automatically. But it will be more difficult to reach the same statistics as that in e^+e^- annihilation at the Z^0 pole.

We calculated the hyperon polarization in different reactions and different kinematic regions [3]. We found it is partcularly interesting that Λ polarization in these reactions are usually small and also the differences from different pictures. On the other hand, polarizations of Σ are larger and the differences between different pictures are also larger. Hence, it should be more sensitive to use Σ as a check to different pictures than to use Λ in these reactions. As an example, we show P_Σ in $\nu_\mu + p \to \mu^- + \Sigma^+ + X$ in Fig.2.

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